CALIFORNIA DIVISION OF MINES AND GEOLOGY

Fault Evaluation Report FER-140

July 29, 1982

1. Name of Fault.

Tolay fault.

2. Location.

Sears Point, Petaluma River, Glen Ellen, Cotati and Two Rock 7.5-minute quadrangles, Sonoma County (see Figure 1).

3. Purpose of Report.

Part of CDMG's Fault Evaluation Program conducted under the Alquist-Priolo Special Studies Zones Act (Hart, 1980).

4. References.

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5. Summary of Available Data.

The Tolay fault is a 22-mile long fault zone that extends from the vicinity of Sears Point on the southeast to the Two Rock quadrangle on the northwest (Figures 3A, 3B). Special Studies Zones were established for the southeastern segment of the fault in 1976 (California Division of Mines and Geology, 1976; see also Figures 1 and 2), primarily based on the work of Armstrong (1974) and Huffman and Armstrong (1980; but in press in 1976) who considered the fault to have been active during Quaternary time. However, the northwestern segment was not zoned at that time because evidence of Quaternary activity was lacking. In 1976, it was CDMG's policy to zone Quaternary faults which were defined as "potentially active". After CDMG's Fault Evaluation Program was initiated, however, only those faults considered to be "active" (Holocene) and well-defined as surface features are zoned (Hart, 1980).

The purpose of this summary is to evaluate the various geologic interpretations of the Tolay fault in terms of the present zoning criteria and to make specific zoning recommendations. The earliest mapping published on the Tolay fault was by Morse and Bailey (1935), who mapped a 2.5-mile segment of the fault in the vicinity of Lakeville School, east of Petaluma. They consider the fault to be a reverse fault dipping 60° SW and having 4500 feet of dip-slip displacement juxtaposing Franciscan rocks (late Mesozoic) against the Petaluma Formation (Pliocene)*. Numerous northeast-trending cross faults also were mapped, somewhat schematically, as offsetting the Tolay fault. The cross faults presumably limit the age of the Tolay fault and suggest a late Pliocene or Quaternary age for the cross faults. However, no evidence of cross faults or other recent faults was apparent on aerial photographs of the area (see below). The fault traces of Morse and Bailey are not plotted on Figure 3A, because the faults are too numerous and their base map is poor. Morse and Bailey's Tolay fault and the cross fault that terminates it on the northwest, are similar to the Tolay fault of Harding-Lawson Associates (1976), which is shown on Figure 3A.

Weaver (1949) mapped most of the Tolay fault (Figure 3A, 3B) showing much of it as inferred or concealed, except in the vicinity of Lakeville School. The youngest units shown to be faulted (Weaver, plates 1, 11 and 13) are the Petaluma Formation (Pliocene)* and Merced Formation (late Pliocene)*. Weaver interprets the Tolay fault to have a vertical dip with the northeast side down several 1000 feet. He suggested that it connects with the Hayward fault to the south. He also shows other faults of similar age, orientation and sense of off-

*According to Sarna-Wojcicki, et al. (1979; USGS Prof. Paper 1147), at least part of the Petaluma Fm. is of late Miocene age, based on radiometric dates of 5.7 to 6.1 m.y. of a tuff unit near Sears Point. Parts of the Merced Fm to the NW (near Sebastopol) are considered to be correlative in age, set, to the west and south. None of the faults shown by Weaver offset Quaternary units, although most of these young units probably are of Holocene age.

Travis (1952) mapped a two-mile long extension of the Tolay fault in the Two Rock quadrangle, where the youngest unit faulted is the Merced Formation of late Pliocene age* (Figure 3B). According to Travis, the post-Merced displacement is "small, mainly vertical" along the steep southwest-dipping fault. He does not suggest that the Tolay or other faults mapped to the west and south are of Holocene or even late Quaternary age. Blake, et al. (1971) map the Tolay fault similarly to Travis.

Cebull (1958) inferred a different location for the southeastern end of the Tolay fault, which he perceived as a steeply southwest-dipping fault concealed under the Merced Formation (Petaluma Formation of others) (Figure 3A). However, he presents no evidence to support the location of the fault and generally accepts the conclusions of Morse and Bailey (1935) regarding geometry, sense and magnitude of displacement, and timing.

Cardwell (1958), in his studies of the groundwater resources of Petaluma Valley, found no evidence that the Quaternary alluvium was faulted or that the ground water was significantly affected where the fault was inferred by Weaver (1949).

Koenig (1963) showed the Tolay fault on the 1:250,000 scale State Geologic map, based largely on the work of Weaver (1949) and Travis (1952). Koenig's only contribution appears to be his concealed connection between the Tolay and Hayward faults. Clement (1965) shows a large (12 to 20 mgal) northeast-sloping gravity anomaly that generally coincides with the Tolay fault. He believes that this anomaly may connect with a similar anomaly along the Hayward-Wildcat fault zone to the south of San Pablo Bay. However, the lack of gravity stations

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*See footnote p. 4.

in San Pablo Bay leaves room for other interpretations and, in any case, he says nothing about the continuity of active faulting.

Sims, et al. (1973) mapped the Tolay fault in the Sears Point quadrangle, showing a more westerly location than Weaver (1949) and Cebull (1958). His traces are partly similar to those of Armstrong (1974). The work of both was used to compile the Special Studies Zones map of that area (Figure 2). Sims, et al. show the youngest units faulted to be Pliocene in age, but they did not designate the fault as "recently active" as they did for the Rodgers Creek fault to the northeast.

The location of the Tolay fault by Blake, et al. (1974) in the Petaluma River quadrangle is partly original and partly similar to Weaver (1949). They show the fault as offsetting late Pliocene beds (Merced Formation), but not the Quaternary alluvium. They did not classify the fault as "recently active", although their work was used to compile the later map of Huffman and Armstrong (1980) and, ultimately, the Special Studies Zones map (Figure 2).

Fox, et al. (1974) relocated the Tolay fault in the Cotati quadrangle, showing it to offset late Pliocene beds but not older alluvium. Their work was adopted by Huffman and Armstrong (1980), which is shown on Figure 3B.

Armstrong (1974) reinterpreted the Tolay fault using geomorphic features observed on aerial photographs, supplemented by field observations. Although no text accompanied this work, it is apparent from the geomorphic features identified that he considered the fault to be a recently active right-lateral fault. Armstrong's information is plotted on Figure 2 and constitutes the primary basis for zoning the southeast segment of the Tolay fault.

Harding-Lawson Associates (1976) attempted to locate the inferred and concealed trace of the Tolay fault near Petaluma to determine if it presents a fault-rupture or seismic hazard to a proposed hospital addition. Based on a review of the literature, field observations, geophysical studies (gravity, seismic refraction, magnetics), and several bore holes made near the hospital site, they concluded that the Tolay fault near Petaluma lies about a mile southwest of the trace of Weaver (1979). They also concluded that the fault is a high-angle reverse fault that dips to the southwest and does not offset Quaternary alluvium. The location of their trace is shown on Figure 3B.

Wesson, et al. (1975, Table 1) in a tabular summary, indicate that there is no evidence that the Tolay fault offsets Quaternary units and that the fault has not been associated with a "significant earthquake." They do state that the fault is associated with geomorphic features that indicate Holocene displacement (C.M. Wentworth, unpublished data), but they do not amplify on this. Presumably, these are the same features noted by Armstrong (1976). They classify the fault primarily as a right-lateral strike-slip fault with significant reverse displacement, but indicate that the fault is not well-mapped in terms of its predicted pattern of surface rupture (this latter seems to conflict with the reported Holocene geomorphic features).

It is interesting to note that Helley and Herd (1977) do not show the Tolay fault to be a Quaternary fault, presumably because of the lack of geomorphic evidence. Their work was based largely on the interpretation of aerial photographs and soil stratigraphy.

Pampeyan (1979), reviewing the work of others, concurred that the youngest units offset by the Tolay fault are Pliocene and locally possibly early Pleistocene in age. He provides no evidence for later displacements.

Huffman and Armstrong (1980, page 19 and plate 3B; was in press 1976) clearly interpret the southeastern segment of the Tolay fault as "potentially active" (i.e. Quaternary) and classify the northwest segment as "possibly active" (i.e. possibly Quaternary) (their Figure 3B). Their fault traces are plotted herein on Figures 3A and 3B. According to Huffman and Armstrong, the "fault related topographic features along the Tolay fault are less distinct than those of the Rodgers Creek fault." However, Huffman and Armstrong cite "several right-lateral offset streams and a large playa lake (Tolay Lake) as suggestive of Quaternary displacement. They cite Sims, et al. (1973), Blake, et al. (1974), Koenig (1963), and Armstrong (1974) as sources of information on fault locations. Additionally, Armstrong (1974) is cited as the basis for the conclusion that the southeastern segment of the Tolay fault is "potentially active" (i.e., Quaternary) and the northwestern segment of the fault is "possibly active" (i.e. possibly Quaternary). They did not connect the two segments with a concealed fault as others did.

Because of the Division's policy of zoning Quaternary faults in 1976 and earlier, the impetus to zone the Tolay fault was provided by Huffman and Armstrong's conclusions that the southeastern segment of the fault was Quaternary in activity. Consequently, this segment was zoned using the original fault trace sources cited in Huffman and Armstrong (Figure 2). The northwestern segment of the Tolay fault was not zoned at that time because it lacked good evidence of Quaternary activity.

6. <u>Interpretation of Aerial Photographs; field observations.</u>

Several sets of aerial photographs were examined stereographically to determine if young fault-related geomorphic features (e.g. offset drainages, linear scarps and troughs, sag ponds, etc.) were developed along the Tolay fault. The best photographs available were those of Sonoma County (1971), U.S. Department of Agriculture (1952-1953), and U.S. Geological Survey (1970; 1973).

Close inspection of these photos failed to reveal any evidence of systematic, Holocene strike-slip or dip-slip displacement along the Tolay fault.

The features identified by Armstrong (1974; Figure 2, herein) could be verified only in part, and many of the features identified by him are believed to be the result of landsliding or differential erosion. In fact, the fault is extensively masked by landslides southeast of the Lakeville School. To the northwest there are few features suggestive (let alone mandatory) of Holocene faulting and no evidence of recent faulting was observed in the alluvium of Petaluma Valley. Observational data of this writer are noted on Figures 2, 3A and 3B.

Except near Lakeville School and locally southeast of there, the Tolay fault is poorly defined and generally not clearly recognizable on aerial photos. In detail, the fault traces of others shown on Figure 2 cannot be verified as being continuous fault strands. My overall impression is that the southeastern segment of the Tolay fault is an oblique-slip fault, (with right-lateral and southwest-dipping reverse components) that was active during Pleistocene (late?) time. This is suggested by 1) the presence of a large, slightly closed depression (Lake Tolay), 2) slight preponderance of right-lateral deflection of drainages and ridges, 3) the intermediate location and orientation of the southeast end of the fault between the active Rodgers Creek and Hayward faults. However, the lack of mutually supportive geomorphic features (e.g. right-lateral offset of several adjacent drainages and ridges, especially in association with aligned troughs, depressions, etc.) indicates a lack of significant Holocene displacement. If Holocene displacement has occurred, then it must be minor and distributive.

Field observations were made at several localities to check for fault creep and for the existence of small-scale geomorphic features that might suggest historic or Holocene displacement, respectively (see Figure 2 for locations).

The roads, curbs and fences near Sears Point, along Highway 37, where it crosses the Tolay fault, were carefully checked for fault creep and none was found. In addition, there were no geomorphic features (other than benches) suggestive of recent faulting on either side of the road. If strike-slip activity exists between the historically active Hayward fault and the seismically active Rodgers Creek fault, this locality is a likely place for creep. In fact, probable creep was identified along the Rodgers Creek fault six miles to the north, where a Holocene-active trace crosses Stage Gulch Road (Figure 2).

The sag ponds and bench noted by Armstrong (1974) just north of Highway 37 also were observed. These features and other benches and hummocky topography are largely distributed in a non-linear manner and are strongly indicative of recent landsliding within the clayey Petaluma Formation. In fact, one fresh landslide scarp along the westerly trace was observed to have 6 inches of dip-slip offset since the last winter. Other youthful scarps are present and generally have arcuate forms suggestive of shallow landsliding. The highly expansive soils and numerous misaligned fences provide abundant evidence of rapid downhill creep and shallow sliding. In addition, telephone poles at the base of the hill along Highway 121 lean outward, indicating deep sliding or lateral spreading of the hillside. This probably accounts for the closed depressions and the large-scale benching. It was noted that the poles were set in bedrock (Petaluma Formation) and not in landslide or soil deposits.

Along Stage Gulch Road, the Tolay fault is concealed by deep soil and landslide deposits. Nearby road cuts expose steeply southwest-dipping shears in Franciscan rocks to the south and steeply north-dipping (dragged?) Petaluma Formation beds to the north. This is suggestive of thrusting from the south. However, the lower topographic position of the Franciscan, even if a fault exists, does not support recent reverse faulting (SW side up).

7. Seismicity.

No significant eathquake has been attributed to the Tolay fault (Wesson, et al., 1975). Also, there is no evidence that well-located earthquakes (A and B quality) are associated with the central or northwestern parts of the Tolay fault (Real, et al., 1978). Seismicity near the southeast segment of the fault probably can be attributed to the Rodgers Creek fault.

8. Conclusions.

The Tolay fault is a 22-mile long, northwest-trending fault or zone of faults that is partly inferred and mostly not well defined as a surface feature. Both the northwestern and southeastern segments offset units of Pliocene age, but no offset units are known to be younger. Although most investigators interpret the fault as steeply southwest-dipping with the southwest side up, they seem uncertain as to the fault's location or even its existence in some places. Indeed, there is no compelling evidence that the northwestern and southeastern segments of the Tolay fault even connect beneath Petaluma Valley. If they do, evidence is lacking that Quaternary alluvium in the valley is offset.

Based on the faults linearity, northwest orientation, and structural relationship to the active Rodgers Creek fault, it appears likely that the Tolay fault is the result of right-lateral strike slip with some reverse movement along steeply southwest-dipping faults.

According to Armstrong (1974) and Huffman and Armstrong (1980), geomorphic features along the southeastern segment of the Tolay fault suggest Quaternary, right-lateral displacement. As a result, Special Studies Zones Maps were established for that segment (California Division of Mines and Geology, 1976).

However, specific evidence of Holocene activity has not been documented, although Wesson, et al. (1975, Table 1) suggest Holocene activity.

Careful interpretation of aerial photos and limited field checking by this writer has failed to identify fault-related geomorphic features that would indicate significant Holocene displacement. Although most of the features identified by Armstrong (Figure 2) are generally verifiable, the lack of clarity and continuity of these features suggest that the features are due variously to pre-Holocene displacement, differential erosion, and landsliding. Indeed, much of the fault to the southeast "Tolay Lake" is partly obscured by landsliding. If the Tolay fault is Holocene active, then such activity is minor, distributive, and restricted to the southwestern end of the fault where it is in close proximity to the well-defined and active Rodgers Creek fault (Figure 2).

Based on geomorphic expression, the Tolay fault is moderately well defined only locally to the southeast of the Lakeville School vicinity. Elsewhere, there is little to suggest the fault's position, let alone its recency.

9. <u>Recommendations</u>.

Under current Division policy, only those faults that meet the criteria of "sufficiently active (i.e. Holocene) and well-defined" are zoned (Hart, 1980). There is no specific evidence that the Tolay fault was active during Holocene time and much of the fault is poorly defined. Therefore, it is recommended that the previously established Special Studies Zones (California Division of Mines and Geology, 1976) be withdrawn. Moreover, SSZ's should not be established for any segment of the fault to the northwest.

10. <u>Report prepared by</u>: Earl W. Hart

Earl W. Hart
July 29, 1982

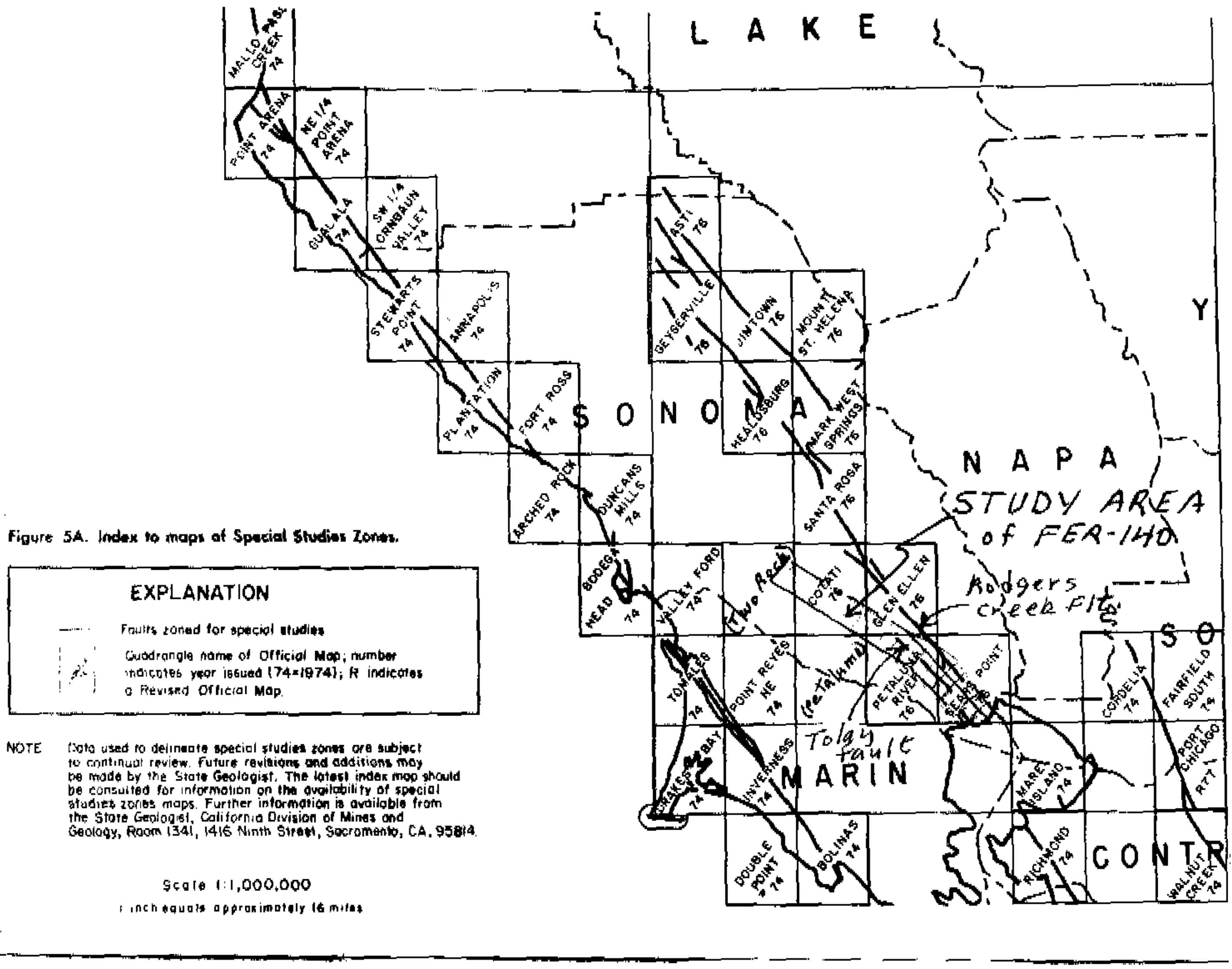

Figure 1 (FER-140). Location map showing the Tolay and other faults zoned for special studies (Hart, 1980) and study area of FER-140.